WPS5673

Policy Research Working Paper 5673

World Oil Price and Biofuels

A General Equilibrium Analysis

Govinda R. Timilsina
Simon Mevel
Ashish Shrestha

The World Bank
Development Research Group
Environment and Energy Team
June 2011

Policy Research Working Paper 5673

Abstract

The price of oil could play a significant role in influencing the expansion of biofuels. However, this issue has not been fully investigated yet in the literature. Using a global computable general equilibrium model, this study analyzes the impact of oil price on biofuel expansion, and subsequently, on food supply. The study shows that a 65 percent increase in oil price in 2020 from the 2009 level would increase the global biofuel penetration to 5.4 percent in 2020 from 2.4 percent in 2009. A doubling of oil price in 2020 from its baseline level, or a 230 percent increase from the 2009 level, would increase the global biofuel penetration in 2020 to 12.6 percent. The penetration of biofuels is highly sensitive to the substitution possibility between biofuels and their fossil fuel counterparts. The study also shows that aggregate agricultural output drops due to an oil price increase, but the drop is small in major biofuel producing countries as the expansion of biofuels would partially offset the negative impacts of the oil price increase on agricultural outputs. An increase in oil price would reduce global food supply through direct impacts as well as through diversion of food commodities and cropland toward the production of biofuels.

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World Oil Price and Biofuels: A General Equilibrium Analysis

Govinda R. Timilsina[1], Simon Mevel and Ashish Shrestha

Key words: Oil Price, Biofuels, Food Supply, CGE Model

JEL Classification: C68, Q18, Q43,

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[1] Corresponding author: Govinda R. Timilsina, Senior Research Economist, Development Research Group, The World Bank. 1818 H Street, NW. Washington, DC 20433, Tel: 1 202 473 2767. Fax: 1 202 522 1151. E-mail: gtimilsina@worldbank.org. The views and findings presented here should not be attributed to the World Bank. We thank Masami Kojima, Omar Osvaldo Chisari for their valuable comments and participants of the 33rd International Conference of the International Association for Energy Economists for discussions. We acknowledge the Knowledge for Change Program (KCP) Trust Fund for the financial support.

1. Introduction

Over the last few years, biofuels have attracted the attention of many stakeholders, including policy makers, industry and academia. Initially, biofuels were seen as an instrument to address climate change and energy security concerns (e.g., Farrell, 2006). Some of the major energy consuming nations took ambitious steps to promote biofuels. However, the food crisis in 2008 lowered enthusiasm for biofuels, which was blamed as a major factor behind the crisis. In addition, carbon neutrality of biofuels is questioned when the emissions they cause through land-use change is taken into consideration. A large number of studies have been completed, or are being conducted, to assess the economy-wide impacts of biofuels[2]. The results of these studies are expected to help policy makers decide whether or not the promotion of biofuels should be pursued further. Despite the large volume of literature, an important aspect of biofuels seems to be ignored, that is, the linkage between oil price and the penetration of biofuels in the transportation fuel mix. This study aims to fill this research gap.

This study uses a multi-country, multi-sector, recursive dynamic, global computable general equilibrium model to examine the research question. The key feature of this model is that it explicitly models the tradeoff between fossil fuels and biofuels. Models lacking such a feature do not capture the indirect effects of oil price on the agricultural sector that occur when a rise in oil price causes the expansion of biofuels, thereby entirely or partially offsetting the negative impacts of the oil price rise on the agricultural production. The model is different from existing models on several fronts, the most important of which is that it models the land-use sector in depth by disaggregating land supply in each country or region into 18 agro-ecological zones. It also explicitly represents major biofuels and their feedstocks.

The study first estimates the share of biofuels (i.e., ethanol and biodiesel) in total liquid fuel consumption for road transportation (hereafter referred to as 'biofuel penetration'). This is followed by assessment of the impacts of increased oil prices on biofuel penetration, agricultural outputs, land-use change and food supply. The study finds that biofuel production very much

[2] Please see Rosegrant et. al (2008), Banse and van Meijl (2008), Ogg (2009), and Timilsina and Shrestha (2010) for recent literature discussing the impacts of biofuels.

affected by changes in oil price -- a 65 percent increase in oil price in 2020 from the 2009 level would increase the global biofuel penetration to 5.4 percent in 2020 from 2.4 percent in 2009. A doubling of oil price in 2020 from its baseline level, or a 230 percent increase from the 2009 level, would increase the global biofuel penetration in 2020 to 12.6 percent. The impacts are highly sensitive to the substitution possibility between biofuels and their fossil fuel counterparts. At the global level, aggregate agricultural outputs drop due to oil price increase, however the drop is small in major biofuel producing countries as the expansion of biofuels would partially offset the negative impacts of oil price increase on agricultural outputs. However, increases in oil price would significantly reduce global food supply.

The paper is organized is as follows. Section 2 briefly presents the CGE model developed for the study along with the associated database. This is followed by the presentation of key results in Section 3, particularly the impacts of an increase in oil price on biofuel penetration in transportation liquid fuel supply as well as on agricultural outputs, land-use and food supply. Section 4 presents results of sensitivity analyses. Finally, Section 5 concludes the paper.

2. Model and data

2.1 The model

We developed a multi-country, multi-sector, recursive dynamic computable general equilibrium model for the purpose of this study. The model is flexible enough to accommodate new regions/countries or sectors. Although the database represents 57 sectors and commodities, we have aggregated some sectors and disaggregated other to arrive at the 27 sectors and commodities as needed for this study. Similarly, the database includes 113 countries, but we have regrouped the countries into 25 countries/regions in the present version of the model. The production sectors have four distinct blocks: a fully disaggregated energy sector identifying biofuels as a separate sub-sector, disaggregated agricultural sector identifying biofuel feedstock as a sub-sector, disaggregated energy-intensive manufacturing sectors (e.g., iron & steel, pulp & paper, etc.) and service sectors. The model has a fuller representation of land types and uses, including crop lands, forest lands, grass lands, etc., as this feature is crucial to capture the economic and environmental impacts of biofuels. The key features of the model structure are briefly presented below.

2.1.1 Production sectors

The production sectors are represented by a set of nested constant elasticity of substitution (CES) specifications (see Figure 1a). At the top tier of the nested structure, a production sector minimizes its production costs (i.e., $X_{i,r} * PX_{i,r} = VAE_{i,r} * PVAE_{i,r} + ND_{i,r} * PND_{i,r}$) subject to the production constraint expressed below in CES functional form:

$$(1)\qquad \begin{aligned} X_{i,r} = [&(\alpha_{i,r}^{VAE})^{1/\sigma_{i,r}^{VAEND}}.(\lambda_{i,r}^{VAE}.VAE_{i,r})^{(\sigma_{i,r}^{VAEND}-1)} \\ &+(\alpha_{i,r}^{ND})^{1/\sigma_{i,r}^{VAEND}}.(\lambda_{i,r}^{ND}.ND_{i,r})^{(\sigma_{i,r}^{VAEND}-1)}]^{\sigma_{i,r}^{VAEND}/(\sigma_{i,r}^{VAEND}-1)} \end{aligned}$$

where X is gross output, VAE is the value added and energy composite, ND is the non-energy aggregate; PX, PVAE and PND are corresponding prices. α^{VAE} and α^{ND} represent scaling factors for VAE and ND, respectively and σ^{VAEND} is the elasticity of substitution between VAE and ND. λ^{VAE} and λ^{ND} are parameters to embody technological change or productivity. Indices i and r refer, respectively, to sector and country or region. Using the first order conditions of the optimization problem above, VAE and ND are derived as follows:

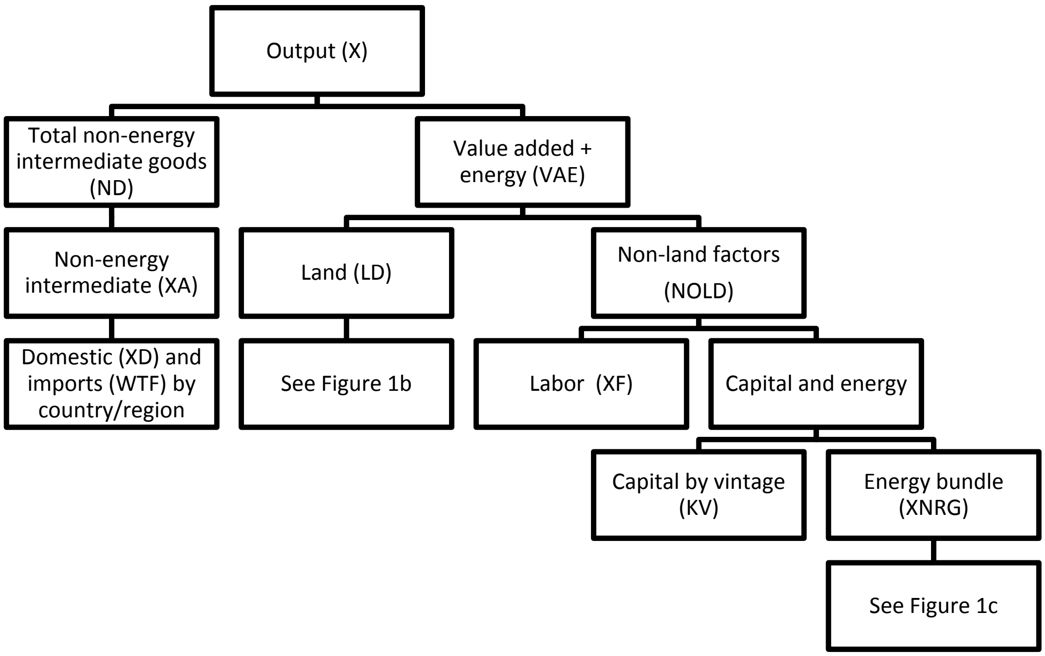
$$(2)\qquad VAE_{i,r} = \alpha_{i,r}^{VAE}.X_{i,r}.(\frac{PX_{i,r}}{PVAE_{i,r}})^{\sigma_{i,r}^{VAEND}}.(\lambda_{i,r}^{VAE})^{(\sigma_{i,r}^{VAEND}-1)}$$

$$(3)\qquad ND_{i,r} = \alpha_{i,r}^{ND}.X_{i,r}.(\frac{PX_{i,r}}{PND_{i,r}})^{\sigma_{i,r}^{VAEND}}.(\lambda_{i,r}^{ND})^{(\sigma_{i,r}^{VAEND}-1)}$$

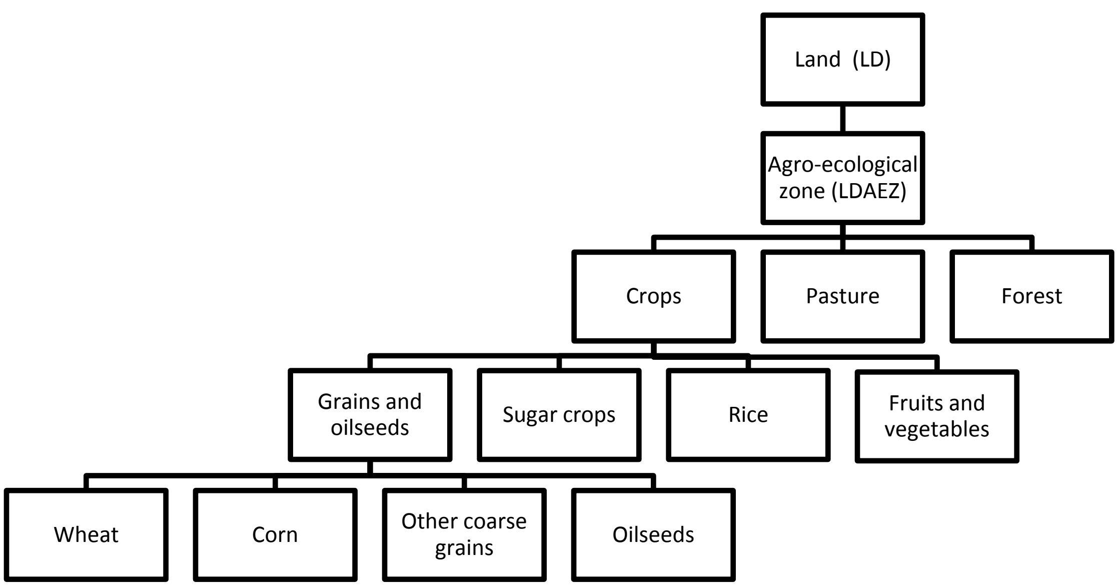
The dual function of Equation (1) is used to derive the production cost as follows:

$$(4)\qquad PX_{i,r} = [\alpha_{i,r}^{VAE}.(\frac{PVAE_{i,r}}{\lambda_{i,r}^{VAE}})^{(1-\sigma_{i,r}^{VAEND})} + \alpha_{i,r}^{ND}.(\frac{PND_{i,r}}{\lambda_{i,r}^{ND}})^{(1-\sigma_{i,r}^{VAEND})}]^{1/(1-\sigma_{i,r}^{VAEND})}$$

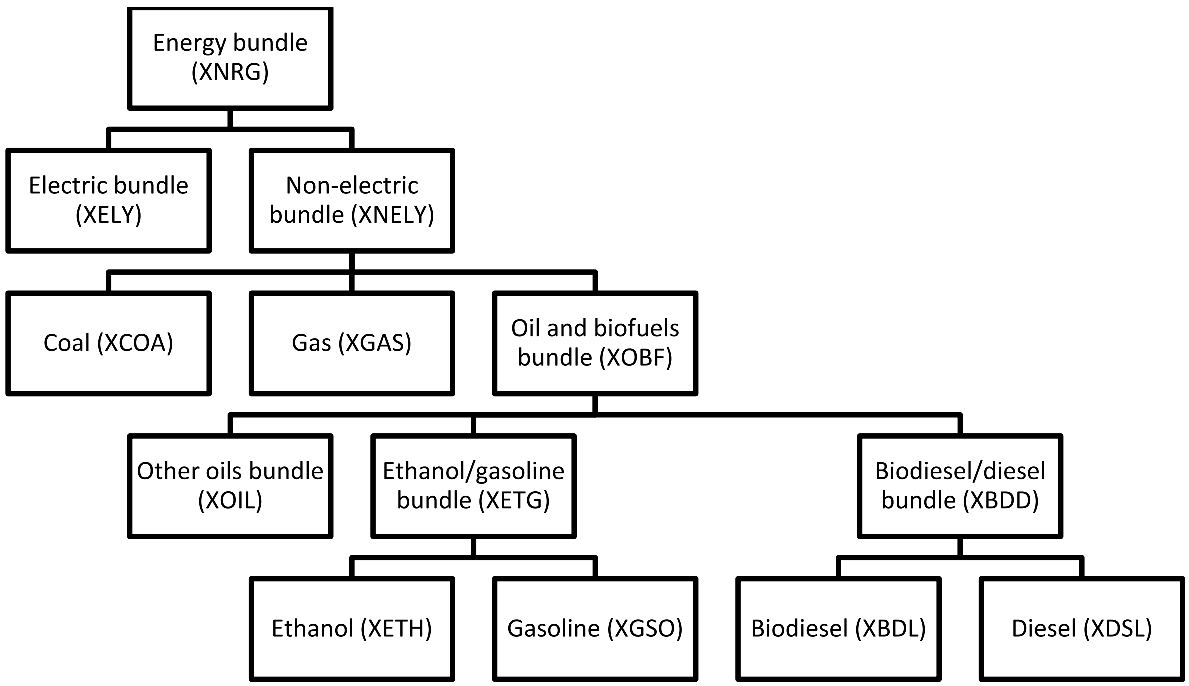
Figure 1: Nested CES structure of the model



(a) Production structure



(b) Land demand structure



(c) Energy demand structure

All other demand variables presented in the subsequent tiers of the nested structures in Figure 1 are derived in a similar manner to Equations (2) to (4). Note that PX is the producers' price prior to the application of a production tax or subsidy and excise tax. The market price for an output (PP) is calculated as follows:

(5) $$PP_{i,r} = PX_{i,r}.(1+\tau^{P}_{i,r}) + \tau^{X}_{i,r}$$

where τ^{P} is a tax (or subsidy) rate applied to production and τ^{x} is an excise tax ($/liter) applied to the sales volume.

Land use changes are incorporated into the model via a CET representation of land supply for each country/region (see Figure 1b). Total land areas are first divided into 18 agro-ecological zones (AEZ) in every country/region. In line with Birur et al. (2008), on the top level of the CET structure, total available land area, under each AEZ, is allocated to forest land, pasture and plantation of crops. On the second level, crops are further divided into four different categories: rice, sugar-crops, grains and oilseeds, and fruits and vegetables. Finally, the grains and oilseeds category is partitioned into wheat, corn, other coarse grains, and oilseeds. This nested structure reflects the reality as not all crops stand in direct competition. For instance, rice typically does not compete directly with other crops for available land. Land use change is induced by changes in relative returns to land. Within each of the CET nests of our land module, agents maximize payoffs by optimally allocating the fixed land area for that nest to the various competing crops. Hence, at the first level, land is optimally divided between forests, pasture and crop land. Given these allocations, profit maximization takes place at the second tier, thus allocating the total available crop land to the four crop categories. Finally, the area designated for grains and oilseeds is optimally allocated among its four sub-categories. This means that changes in the relative returns to land use types lead to a reallocation of acreage to the various categories, leading to land use changes such as deforestation. A detailed description of the model is available in Timilsina et al. (2010).

Since the purpose of the study is to examine the impacts of oil price on biofuel penetration, we have explicitly modeled the biofuel sectors. As shown in Figure 1c, the total demand for energy is a CES composite of electricity and an aggregate of non-electric energy commodities. One component of the latter is the liquid fuel, which a CES composite of the ethanol-gasoline and diesel-biodiesel bundles. The model allows direct substitution between gasoline and ethanol, and between diesel and biodiesel.

2.1.2 The household sector

Per capita utility from private household expenditures is modelled using a nonhomothetic Constant Difference of Elasticities (CDE) function. The CDE implicit expenditure function is expressed as follows:

$$(6) \qquad \sum_k \alpha^{HH}_{k,r,h} . U_{r,h}^{e^{HH}_{k,r,h} . b^{HH}_{k,r,h}} . \left(\frac{PHX_{k,r,h}}{UYC_{k,r,h}}\right)^{b^{HH}_{k,r,h}} \equiv 1$$

where U is household utility, and PHX is the price of household consumption of individual goods. Indices k, r, and h refer to commodity goods/services, region/country and household type, respectively. The individual prices (PHX) are normalized with per capita expenditure (UYC) and then raised to the power b to combine in an additive form (Ianchovichina et al. 2002). The volume of aggregate private consumption (XC) is derived by dividing aggregate household expenditure (YC) by a consumer price index (PC), which is calculated as:

(7) $$PC_{r,h} = \sum_{k} s^{HH}_{k,r,h}.PHX_{k,r,h} \text{ where } s^{HH}_{k,r,h} = \frac{PHX_{k,r,h}.HX_{k,r,h}}{YC_{r,h}}$$

HX is household demand for individual goods and services and is obtained by multiplying population by per capita consumption of individual goods and services. Household savings (S^{HH}) is calculated by applying a household saving rate (s^{s}) to disposable income (YD). Household saving rate is a function of per capita consumption growth (g^{pc}) and the ratios of population below age 15 (RAGE15) and above age 65 (RAGE65).

(8) $$S^{HH}_{r,h} = s^{s}_{r,h}.YD_{r,h}$$

(9) $$s^{s}_{r,h} = \chi^{s}_{r}.\alpha^{s}_{r,h} + \beta^{s}_{r}.s^{s}_{r,h,-1} + \beta^{g}_{r}.g^{pc}_{r} + \beta^{y}_{r}.RAGE15_{r} + \beta^{e}_{r}.RAGE\,65_{r}$$

2.1.3 The government sector

The model accounts for six types of indirect taxes and a household income tax (τ^{IN}) when calculating total government revenue (GREV). The indirect taxes are: (i) the output tax (τ^{P}) imposed on the output price (PX) with an additional excise tax (τ^{x}) in some circumstances; (ii) a sales tax on domestic sales of Armington goods (τ^{A}) imposed on the economy-wide price of Armington goods (PA); (iii) bilateral import tariff or duty (τ^{m}) imposed on the CIF price of imports (WPM); (iv) bilateral export tax or subsidy (τ^{e}) imposed on the producer price of exports (PE); (v) taxes on factors of production (τ^{v}) imposed on market clearing price factors and (vi) taxes on emissions (τ^{EMI}) imposed on the consumption of Armington goods. Total government revenue is then calculated as follows:

(10) $$\begin{aligned} GREV_{r} &= \sum_{i}(\tau^{p}_{i,r}.X_{i,r}.PX_{i,r} + \tau^{x}_{i,r}.X_{i,r}) + \sum_{i,k}\tau^{A}_{i,k,r}.XA_{i,k,r}.PA_{i,k,r} \\ &+ \sum_{i,rr}\tau^{m}_{i,rr,r}.PM_{i,rr,r}.BTF_{i,rr,r} + \sum_{i,rr}\tau^{e}_{i,r,rr}.PE_{i,rr,r}.BTF_{i,r,rr} + \sum_{i,f}\tau^{v}_{i,r,f}.PF_{i,r,f}.XF_{i,r,f} \\ &+ \sum_{i,em,k}\tau^{EMI}_{em,r}.\eta_{em,k,i,r}.XA_{k,i,r} + \sum_{h}\tau^{IN}_{r}.YH_{h} \end{aligned}$$

where BTF is bilateral trade flow and YH is total household income raised through factors owned by households (e.g., labor, land, capital). η is the emission coefficient per dollar value of a commodity (i.e., CO_2 emission per dollar consumption of a good or service).

2.1.4 International trade

The total (or Armington) demand for a good XA is assumed to be a CES composite of its domestic components (XD) and imported components (XM) and expressed as follows:

$$(11) \qquad XA_{k,r} = [(\alpha^{XD}_{k,r})^{1/\sigma^{A}_{k,r}}.XD_{k,r}^{\frac{(\sigma^{A}_{k,r}-1)}{\sigma^{A}_{k,r}}} + (\alpha^{XM}_{k,r})^{1/\sigma^{A}_{k,r}}.XM_{k,r}^{\frac{(\sigma^{A}_{k,r}-1)}{\sigma^{A}_{k,r}}}]^{\sigma^{A}_{k,r}/(\sigma^{A}_{k,r}-1)}$$

where α^{XD} and α^{XMT} are scaling factors of XD and XMT; and σ^{A} is the Armington elasticity of substitution; k is the index representing commodities. In a similar manner to Equations (2) to (4), demand and price variables are derived as follows:

$$(12) \qquad XD_{k,r} = \alpha^{XD}_{k,r}.XA_{k,r}.(\frac{PA_{k,r}}{PD_{k,r}})^{\sigma^{A}_{k,r}}$$

$$(13) \qquad XM_{k,r} = \alpha^{XMT}_{k,r}.XA_{k,r}.(\frac{PA_{k,r}}{PM_{k,r}})^{\sigma^{A}_{k,r}}$$

$$(14) \qquad BM_{k,r,rr} = \alpha^{XM}_{k,r,rr}.XM_{k,r}.(\frac{PM_{k,r}}{(1+\tau^{m}_{k,r,rr}).WPM_{k,r,rr}})^{\sigma^{A}_{k,r}}$$

where, BM is the bilateral imports from region rr and WPM is the ex-duty import price of a good, which is nothing but the export price of the good in the exporting country adjusted by transportation margins and export tax/subsidy. The Armington price of a good is then expressed as a CES composite of domestic and import prices:

$$(15) \qquad PA_{k,r} = [\alpha^{XD}_{k,r}.PD_{k,r}^{(1-\sigma^{A}_{k,r})} + \alpha^{XMT}_{k,r}PM_{k,r}^{(1-\sigma^{A}_{k,r})}]^{1/(1-\sigma^{A}_{k,r})}$$

The import price of a commodity is an aggregate of the bilateral import prices of that commodity across the trade regions, i.e.,

$$(16) \qquad PM_{k,r} = [\sum_{rr}\alpha^{XM}_{k,r,rr}.\{(1+\tau^{m}_{k,r,rr}).WPM_{k,r,rr}\}^{(1-\sigma^{A}_{k,r})}]^{1/(1-\sigma^{A}_{k,r})}$$

where, rr is the source of the imported goods and WPM is the CIF price of imports. In the case of export demand, the model considers a two-tiered nested CET structure. At the top tier, output is allocated to domestic and export markets. At the bottom tier, aggregate exports are allocated to various foreign markets. The bilateral export demand from a region r to a region rr is calculated as follows:

(17) $$XE_{k,r,rr} = \alpha^{XE}_{k,r,rr} . XE_{k,r} . (\frac{PW_{k,r,rr}}{PP_{k,r}})^{\sigma^{A}_{k,r}}$$

where, α^{XE} is the scaling factor of export demand and PW is export price. At the global level, net trade (NT) of homogenous goods equal to zero.

(18) $$\sum_{r} NT_{r,hg} = \sum_{r} PW_{r,hg} . (XE_{r,hg} - XM_{r,hg}) = 0$$

where, hg is an index representing homogenous commodities and PW is the world price.

2.1.5 Market clearing

Goods/service market clearing: Total goods produced in a country/region are allocated to domestic consumption and exports. The net of tax sectoral return is equal to the economy-wide return, thereby holding the law of one price for an economy as a whole.

Factor market clearing: Capital supply is specified by vintage. New capital is perfectly mobile across sectors, insuring a uniform rate of returns. If there are no sectors with declining economic activities (i.e., outputs), a single economy-wide rate of return on capital will prevail. The total capital stock in the economy is assumed to be unchanged as a result of a policy change. Moreover, the rate of return to a sector specific factor is assumed to rise at the same rate as the GDP deflator.

Macro closure: Total investment is equal to total savings, which includes household savings, government savings and foreign savings. Government savings is the difference between total government income and government expenditure. The later is maintained as a fixed share of nominal GDP. The government balance is achieved with a uniform shift in the direct tax schedule, implying that revenue from a new tax in a policy would lower the direct tax paid by households. Foreign savings is defined exogenously and is kept fixed.

2.1.6 Model dynamics

The endogenous driver of the dynamics in the model is the vintage capital structure. The capital stock is composed of old and new capital, where new corresponds to the capital investments at the beginning of the period and old corresponds to the capital installed in previous periods. The ratio of new to old capital is also a measure of the flexibility of the economy, as new capital is assumed to be perfectly mobile across sectors. Furthermore, each period, a fraction of the old capital depreciates. Population and productivity growth are exogenous drivers of the model's dynamics. The former is taken from the projections of the United Nations Population Division, where labor force growth corresponds to growth of the population aged 15-64 years. Productivity growth is modeled as exogenous and factor neutral for agricultural sectors and labor augmenting for industrial and service sectors. Productivity of energy follows an autonomous energy efficiency improvement (AEEI) path so that there is no endogenous technological change in the model.

2.2 Data

Like in any CGE model, the main data needed are in two folds: (i) social accounting matrix (SAM) and (ii) elasticity parameters. In this section, we briefly introduce the data used for the study. For more detailed information, please refer to Timilsina et al. (2010).

2.2.1 The Social Accounting Matrix

For SAM, the model uses the GTAP database (Narayanan and Walmsley, 2008). However, the database has been substantially updated for the purpose of this study. First, we have introduced corn as a separate sector/commodity, whereas it was included in "other cereal grains" in the GTAP database. The splitting process was implemented through a program called Splitcom (Horridge, 2008). A significant amount of data was required to perform the split, including information on production, consumption and trade flows for corn and other cereal grains. Detailed documentation on the splitting process and the data required to execute the sectoral split is available upon request to the authors. Second, the GTAP database does not have biofuel sectors, so we specified sectors for ethanol and biodiesel. Moreover, we introduced three sub-sectors for ethanol: corn-based ethanol; sugar-based ethanol (i.e., ethanol produced from sugar cane and sugar beet) and other grains-based ethanol (i.e., ethanol produced from wheat and other cereal grains). We also added three biodiesel sub-sectors for biodiesel produced from oilseeds, soybeans and palm oil[3].

[3] Interested readers could request unpublished documentation describing all the steps needed in introducing these critical sectors into the GTAP database from the authors.

2.2.2 Elasticity parameters

Most of the elasticity parameters are taken from the literature. Since the results are sensitive to some elasticities, special attention was paid while choosing the values for elasticity of substitution between biofuels and competing fossil fuels. Birur et al. (2008) collect historical data allowing them to determine a default value of 2.0 for this elasticity parameter. Yet, they point out the lack of data availability for conducting econometric analysis and they acknowledge that the value could vary significantly across countries (especially if a country is already equipped with flex-fuel vehicles or not). After several sensitivity analyses varying this parameter, we decided to nearly triple its value overtime, between 2004 and 2020, from 1.2 to 3.0 for all countries. We think it is realistic with future expansion of flex-fuel vehicles and we prefer not to consider higher values as they would tend to accelerate biofuel penetration too rapidly.

In our CGE model, we split total land into 18 Agro-Ecological Zones (AEZs) depending on climate type and humidity levels of the land (Hertel et al. 2009). We use a CES functional form with a high value of 20 for substitution elasticity between AEZs. For a given AEZ, the land supply is constrained across the different land-specific uses with nested constant elasticity of transformation (CET) functional forms. Following Hertel et al. (2008) we select -0.2 for the first level of the structure but consider the same values as Choi (2004) with respectively -0.5 and -1 for the next second levels. We apply the same elasticities for all countries.

Values for other elasticities (as shown in Figures 1a-c), are taken from Burniaux and Chateau, OECD (2010); van der Werf (2008); Timilsina and Shrestha (2006); Ma et al. (2010); Jarrett and Torres (1987) and Narayanan and Walmsley (2008).

3. Key results from model simulations

We considered three simulations for this analysis: increase in oil prices by 25%, 50% and 100% from their corresponding baseline values starting from 2012. While alternative scenarios, for example, different growth rates for oil prices as compared to that in the baseline, could be developed, the results would be the same for the terminal year of the study horizon although impacts for earlier years would be lower in the latter case as compared to that in former case.

Table 1 presents oil prices under various scenarios and corresponding percentage changes from the current (i.e., 2009) price level. For example, a 50% increase in oil price from the baseline in 2020 refers to a 147% increase as compared to the 2009 level.

Table 1: Oil prices and percentage changes from the current (i.e., 2009) price level

Year	Baseline	Scenario		
		25%	50%	100%
US$/barrel (2008 price)				
2009	56			
2010	67			
2015	87	109	130	174
2020	93	116	140	186
% Change from 2009 level				
2009	0			
2010	19			
2015	54	92	131	208
2020	65	106	147	230

Source: EIA (2009) and IEA (2009) for baseline data for period 2009-2015.

3.1 Impacts on biofuel production and penetration in transportation fuel mix

Table 2 presents the production of biofuels in monetary value in the baseline and the percentage increase from the baseline under various scenarios for oil price increase. As can be seen from the table, global biofuel production in 2020 would be more than double than that in year 2009. Middle/low income countries are found responsible for a larger share the output in 2020 than high income countries. It is interesting to note that production of biofuels is highly sensitive to oil price. For example, a 25% increase in oil price from the baseline in 2020 (i.e., a 107% increase from the 2009 level), would cause a 20.4% increase in global biofuel production. Similarly, a 100% increase in oil price from the baseline in 2020 (i.e., a 230% increase from the 2009 level), would cause a 77.3% increase in global biofuel production. The impacts, however, vary significantly across countries (see Table 2 for the detailed results).

The penetration of biofuels in the transport sector under various scenarios for oil prices are presented in Figure 2. In the base case, the share of ethanol and biodiesel in total liquid fuel consumption in the road transport sector would increase from 2.4% in 2009 to 5.4% in 2020. If, starting from 2012, oil price increases by 25% from that in the baseline, the penetration of biofuels would reach around 7.2% in 2020, the incremental change relative to baseline is about 2%. In other words, the penetration of biofuels at the global aggregate level would reach 7.2% in 2020 if the price of oil rises by 107% relative to the 2009 level. If oil price doubles from the baseline level (i.e., a 230% increase from the 2009 level), the penetration of biofuels would exceed 12% in 2020.

Table 2: Biofuels production in 2020 due to oil price increase

Region/Country	Baseline (2004 US$ Billion)	% change from the baseline in oil price scenarios		
		25%	50%	100%
World total	**60.1**	**20.4**	**40.0**	**77.3**
High-income	**28.3**	**20.6**	**40.5**	**78.1**
Australia and New Zealand	0.2	25.9	52.4	107.6
Japan	0.4	25.2	51.4	106.1
Canada	0.5	21.4	42.5	83.8
United States	18.3	19.1	37.2	70.3
France	2.9	23.5	46.8	92.7
Germany	3.0	21.6	42.6	82.5
Italy	0.8	25.4	51.3	104.1
Spain	0.8	26.1	52.7	107.5
UK	0.5	23.4	46.9	93.8
Rest of EU & EFTA	1.1	23.3	46.6	93.4
Middle & Low-income	**31.8**	**20.2**	**39.7**	**76.6**
China	4.0	24.0	47.6	93.1
Indonesia	0.7	32.9	67.8	141.6
Malaysia	0.5	24.9	49.6	97.9
Thailand	0.4	25.9	51.2	99.5
Rest of East Asia & Pacific	0.2	30.8	63.4	133.5
India	1.9	43.3	91.5	198.9
Rest of South Asia	0.1	30.3	62.8	133.6
Argentina	0.3	27.5	56.1	115.6
Brazil	20.2	15.1	28.2	50.2
Rest of LAC	0.3	39.0	83.6	189.3
Russia	1.7	27.0	54.5	110.9
Rest of ECA	0.6	23.2	46.2	91.6
MENA	0.1	33.1	69.1	148.7
South Africa	0.6	25.9	51.0	97.7
Rest of Sub-Saharan Africa	0.2	43.0	92.6	210.0

Note: EFTA stands for European Free Trade Association; LAC, ECA and MENA refer to respectively, Latin America and Caribbean, Eastern Europe and Central Asia and Middle East and North Africa.

Figure 2: Impacts of oil price increase on biofuel penetration at the global level (%)

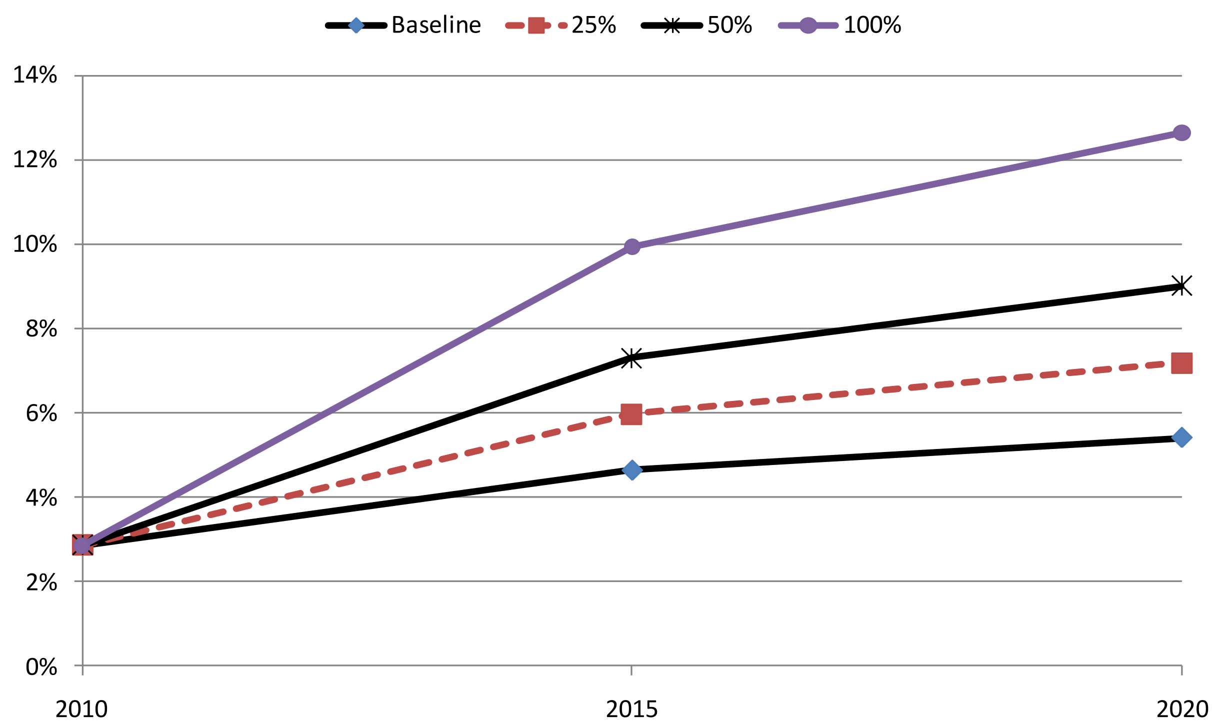


Table 3 delivers further insights by presenting the penetration of biofuels in different countries and regions under alternative scenarios of oil price increase. As expected, higher oil price would further increase penetration of biofuels in Brazil, where biofuels currently accounts for around 10% of the total liquid fuel consumption, in terms of energy unit, in the transport sector (excluding jet fuels and heavy fuel oils). The share of biofuels in Brazil would reach around 28%% in 2020 if oil price doubles from its baseline level. Other countries that would experience significant penetration of biofuels if oil price doubles from its baseline level include the United States, Malaysia, India and Russia, where biofuel penetration would exceed 15%.

Table 3: Penetration of biofuels in 2020 due to oil price increase
(Biofuels consumption as percentage of the total liquid fuel consumption for transportation)

Region/Country	Baseline	Scenarios		
		25%	50%	100%
World total	**5.4**	**7.2**	**9.0**	**12.6**
High-income	**4.4**	**5.9**	**7.4**	**10.5**
Australia and New Zealand	0.9	1.2	1.6	2.4
Japan	1.1	1.6	2.0	3.1
Canada	2.7	3.7	4.7	7.1
United States	7.7	10.0	12.3	16.7
France	4.4	6.1	7.9	11.8
Germany	5.8	7.9	10.1	14.7
Italy	2.7	3.8	4.9	7.5
Spain	2.3	3.2	4.2	6.4
UK	0.9	1.2	1.6	2.5
Rest of EU & EFTA	1.6	2.2	2.9	4.3
Middle & Low-income	**6.9**	**9.0**	**11.2**	**15.5**
China	5.0	6.9	8.9	13.0
Indonesia	4.2	6.1	8.2	12.9
Malaysia	6.1	8.8	11.8	18.2
Thailand	3.3	4.8	6.4	10.0
Rest of East Asia & Pacific	1.0	1.4	1.9	3.1
India	6.3	9.3	12.7	20.1
Rest of South Asia	0.9	1.2	1.7	2.7
Argentina	3.8	5.4	7.2	11.2
Brazil	18.8	21.7	24.1	27.6
Rest of LAC	2.3	3.4	4.6	7.6
Russia	7.1	9.8	12.7	18.5
Rest of ECA	2.3	3.1	4.0	5.9
MENA	0.2	0.3	0.4	0.6
South Africa	5.6	7.6	9.6	13.6
Rest of Sub-Saharan Africa	3.5	5.1	7.1	11.6

What is the biofuel penetration level corresponding to currently announced targets in different countries? And what is the magnitude of the oil price increase that would be required for those targets to be met through the rise in oil price? Table 4 presents this for year 2020 as biofuels targets are supposed to be met by 2020 in several countries. The table offers some interesting observations. In the United States, for example, biofuel penetration in year 2020 corresponding to its announced target is 4.1%. The 48.5% rise in oil price from 2009 to 2020 that is captured in the baseline would be more than sufficient to increase biofuel penetration in the United States to its target level without any further increases in oil price. This does not mean, however, that a rapid increase in oil price today would result in the announced targets being reached overnight because the biofuels or the hybrid vehicle fleet required to meet the targets do not exist. Over time, the fleet is expected to be built, and by 2020, the target could be met in response to increasing oil price. Some countries/regions, such as Japan and Latin America and the Caribbean (excluding Brazil and Argentina), have such low targets that they could meet them much earlier than 2020 under the baseline.

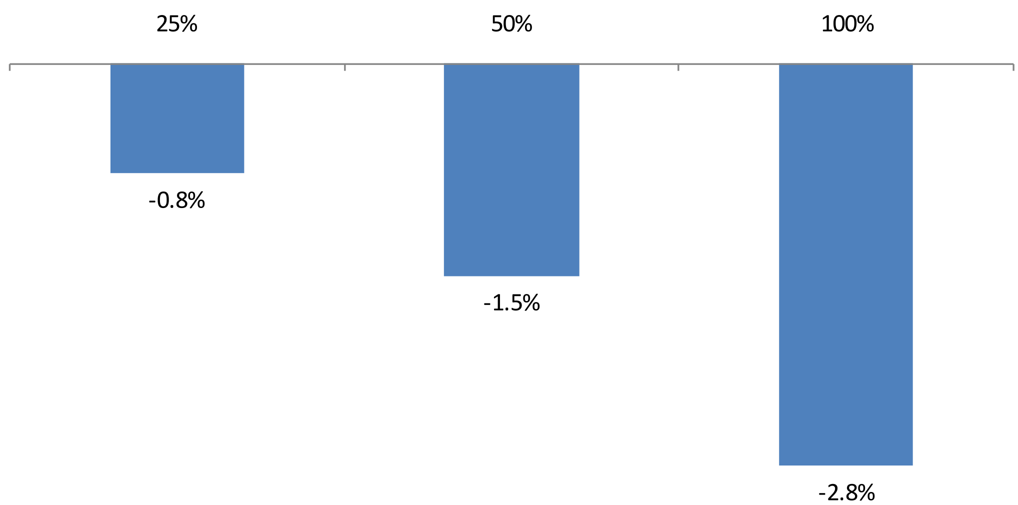
Table 4: Biofuel penetration in 2020 corresponding to already announced targets and required oil price increase if those targets were to be met through oil price hike

Region/Country	Biofuel penetration corresponding to announced targets (%)	% increase in oil price from the baseline level	% increase in oil price from the 2009 level
Australia and New Zealand	1.2	13.4	86.9
Japan	0.6	0.0	22.2
Canada	4.1	44.1	138.0
United States	4.1	0.0	48.5
France	10.0	71.8	184.0
Germany	10.0	47.8	143.5
Italy	10.0	167.2	344.0
Spain	10.0	187.1	377.1
UK	10.0	514.2	932.5
Rest of EU & EFTA	10.0	351.8	652.1
China	3.7	35.4	111.5
Indonesia	5.0	26.6	101.9
Malaysia	1.8	0.0	0.6
Thailand	5.2	47.6	143.4
Rest of East Asia & Pacific	1.5	31.5	113.4
India	16.7	107.1	244.7
Rest of South Asia	-		
Argentina	5.0	31.4	114.9
Brazil	9.5	0.0	11.3
Rest of LAC	1.5	0.0	49.6
Russia	-		
Rest of ECA	-		
MENA	-		
South Africa	2.0	0.0	21.3
Rest of Sub-Saharan Africa	-	-	-

3.2 Impacts on agricultural outputs

Figure 3 presents impacts of oil price increase on total agricultural output at the global level under different scenarios. As can be seen from the figure, a 25% increase in oil price from the baseline would reduce global agricultural output by 0.8% in 2020. If oil price doubles from its baseline level (or increases by 100%), global agriculture output would decrease by almost 3% in 2020. Note that the loss in agriculture outputs would be even higher if there were no biofuels, which provides incentives to increase agricultural output, thereby partially offsetting the losses in agricultural output caused by the oil price rise.

Figure 3: Impacts of oil price increase on agricultural outputs in 2020 (% change from the baseline)



Countries where the agricultural sector is relatively more energy intensive would suffer more from the oil price increase (see Figure 4). These countries include all developed or high income countries as well as some middle income countries, such as Argentina, South Africa and Thailand. Sub-Saharan Africa, excluding South Africa, exhibits an increase in agricultural output due to an oil price rise for two reasons: first, the agricultural sector in this region consumes less commercial energy as compared to other regions; second, biofuels expansion caused by the oil price increase would lead to an increase in agricultural output. In fact, the increase in agricultural output due to biofuels would be higher than the decrease due to the oil price rise, resulting in a net increase in agricultural output.

Figure 4: Impacts of oil price increase on agricultural outputs in 2020 (% change from the baseline)

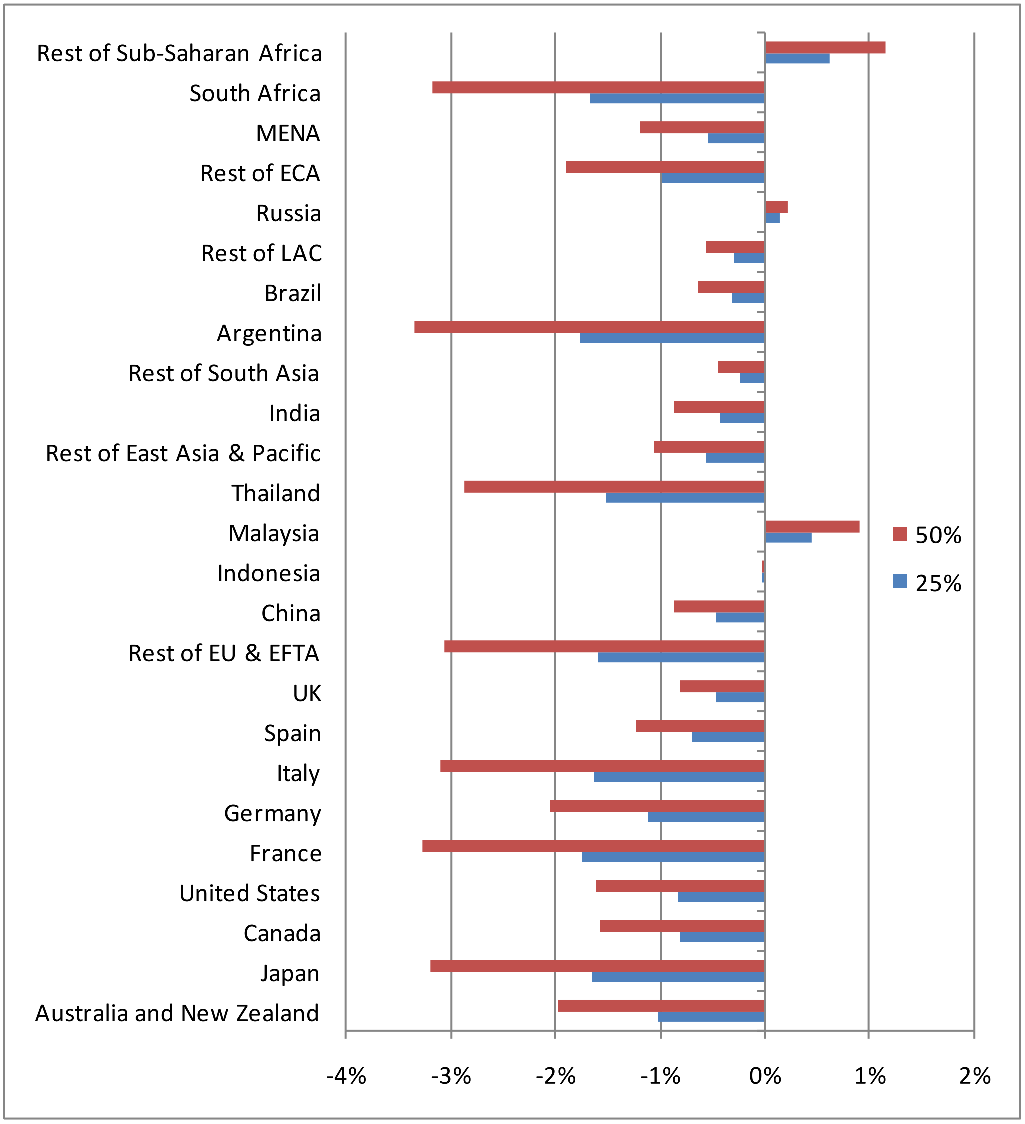


Table 5 offers more insights by presenting the impacts of an oil price increase (50% higher than in the baseline) on different types of crops. An interesting observation from the table is that the production of some key biofuel feedstocks (e.g., sugar crops and corn) are increasing as the rise in oil price causes the expansion of biofuels. On the other hand, production of livestock, rice and fruit & vegetables would decrease. This is because the increase in biofuels caused by oil price rise would cause land relocation from livestock, rice, fruit and vegetables, which are not used for biofuel production to corn and sugarcane, which are used for biofuel production. Moreover, the livestock, rice and fruits & vegetables sectors are more energy intensive as compared to other crop sectors.

Table 5: Impacts of oil price increase by 50% on outputs of various crops in 2020 (% change from the baseline)

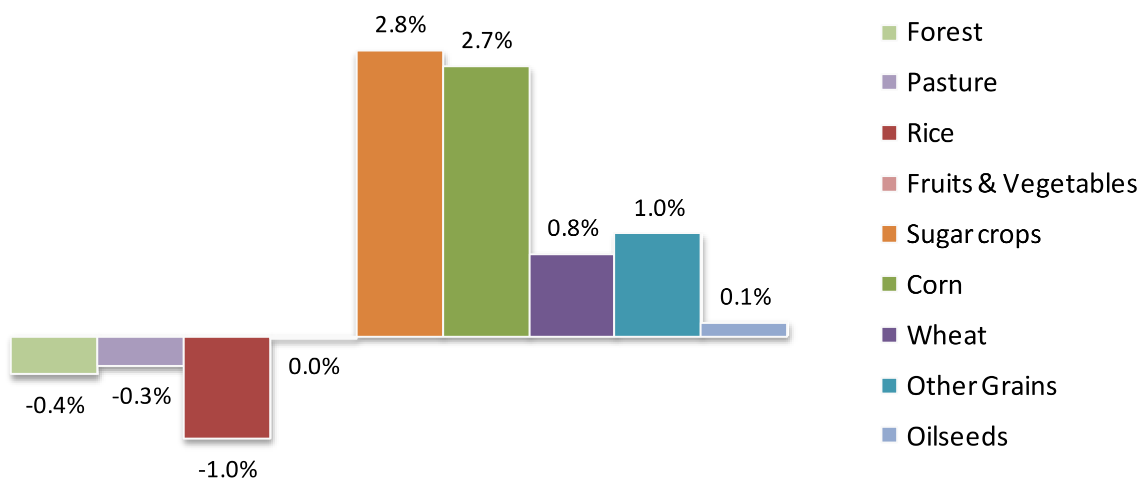
Country/Region	Rice	Sugar crops	Fruits & vege.	Wheat	Corn	Other grains	Oil Seeds	Livestock
World total	**-2.0**	**3.2**	**-1.7**	**-0.5**	**2.2**	**0.3**	**-1.0**	**-2.1**
High-income	**-2.7**	**0.1**	**-2.3**	**-0.7**	**3.3**	**0.4**	**1.1**	**-3.4**
Australia and New Zealand	-4.2	-0.5	-2.8	3.5	1.7	3.4	1.2	-2.5
Japan	-2.2	3.9	-3.4	5.5	9.1	4.3	6.5	-4.3
Canada	0.0	0.7	-2.5	2.4	4.4	-2.1	-1.5	-2.0
United States	-5.7	-1.2	-1.3	-4.4	5.3	-1.6	-1.4	-3.0
France	-2.4	9.5	-3.1	-4.9	-6.2	-0.6	3.2	-4.2
Germany	0.0	-0.6	-1.5	-2.4	-3.1	0.0	10.4	-3.7
Italy	-8.5	-1.0	-3.1	-2.9	-2.9	-0.3	2.1	-3.7
Spain	-0.9	-1.3	-1.5	6.8	2.7	6.5	2.6	-3.0
UK	0.0	0.6	-0.9	4.5	0.0	3.8	5.1	-1.9
Rest of EU & EFTA	-3.7	-3.0	-3.1	2.3	2.2	-0.5	4.0	-4.3
Middle & Low-income	**-1.9**	**4.2**	**-1.2**	**-0.3**	**1.4**	**0.2**	**-2.1**	**-0.7**
China	-2.6	0.4	-0.7	0.8	2.1	2.4	0.2	-1.2
Indonesia	-1.8	9.6	0.3	0.0	0.6	0.0	2.0	-1.2
Malaysia	-3.6	-0.7	5.8	0.0	0.0	10.7	6.5	-0.3
Thailand	-4.3	9.9	-2.1	0.0	0.0	1.4	3.4	-6.7
Rest of East Asia & Pacific	-1.8	1.5	-0.3	3.8	4.6	-8.1	6.3	-2.0
India	-2.8	3.5	0.5	-3.0	-2.3	-2.8	-2.7	-1.3
Rest of South Asia	-0.6	0.2	0.5	1.6	2.4	-0.2	4.2	-1.5
Argentina	-11.9	-1.5	-5.0	-1.3	-1.3	-2.7	-4.7	-1.6
Brazil	1.0	16.9	-2.4	4.5	3.8	1.7	-3.4	-0.5
Rest of LAC	0.2	1.8	-2.0	2.2	2.8	1.8	-0.6	-0.3
Russia	-0.8	-1.2	-1.1	6.8	0.1	0.1	-1.2	0.0
Rest of ECA	-2.0	-2.0	-1.6	-1.2	-2.1	-0.9	-3.2	-2.4
MENA	0.9	-2.7	-3.6	1.5	-6.0	-1.0	-2.6	1.9
South Africa	0.0	16.4	-6.7	-4.3	-0.6	-0.8	-1.2	-2.4
Rest of Sub-Saharan Africa	0.0	2.4	-0.3	2.8	3.1	2.7	2.2	3.2

Whether or not the production of an agricultural commodity is negatively impacted by an increased oil price also depends on the oil intensity of production. In some countries, such as Argentina and Italy, a 50% rise in oil price from its baseline level (i.e., a 148% increase from the 2009 level) would cause rice production to drop substantially as rice production in these countries is more oil intensive than in other countries. Agricultural production in major biofuel producing countries, like Brazil, Indonesia and Malaysia, is not affected much by the increased oil price. This is because the expansion of biofuels feedstocks, particularly sugarcane, caused by the oil price increase can almost offset any regressive impacts of the oil price rise on the agricultural sector. In addition to this effect of the expansion of biofuel feedstocks, oil price increase does not adversely affect the production of any of the agricultural commodities in Sub-Saharan Africa (excluding South Africa) because of the lower share of oil in the total energy use for production of agricultural commodities.

3.3 Impacts on land-use change

The changes in agricultural production due to an increase in oil price can be explained by examining the land-use changes caused by biofuel expansion. Figure 5 illustrates the change in land-use due to a 50% increase in oil price from the baseline. As explained earlier, the increase in oil price would raise demand for biofuels, which would then tilt land allocation towards biofuel feedstocks. For example, a 50% increase in oil price from the baseline in 2020 (i.e., a 148% increase from 2009 level) would expand land for corn and sugar cane cultivation by more than 2.5%. This expansion of land would come at the expense of land used for rice cultivation, pasture and forest. Land used for rice cultivation could drop by 1%. This clearly explains why an increase in oil price causes a significant drop in rice production in major rice producing countries.

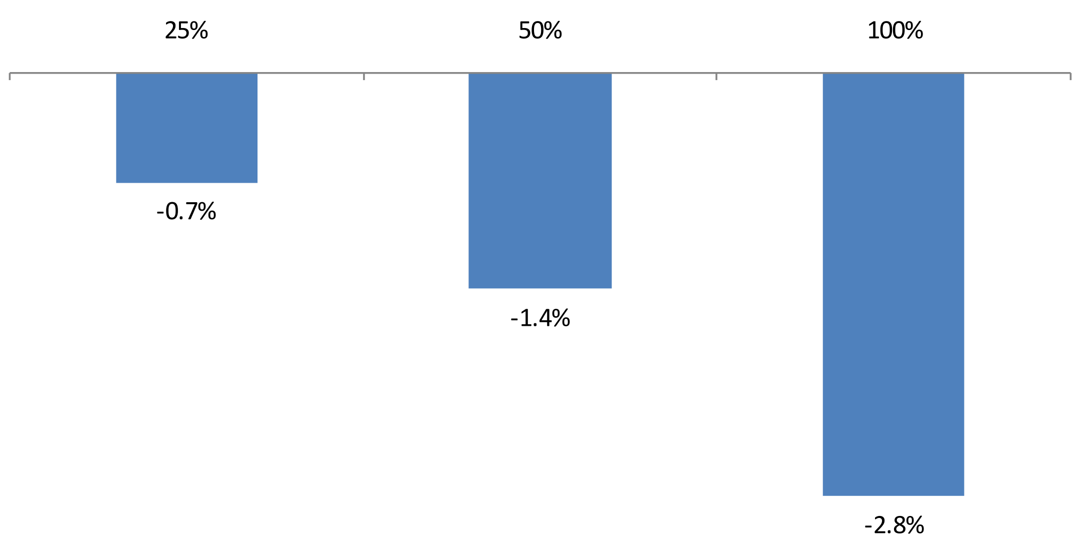
Figure 5: Impacts of oil price increase by 50% on global land-use change (% change from the baseline)in year 2020



3.4 Impacts on food supply

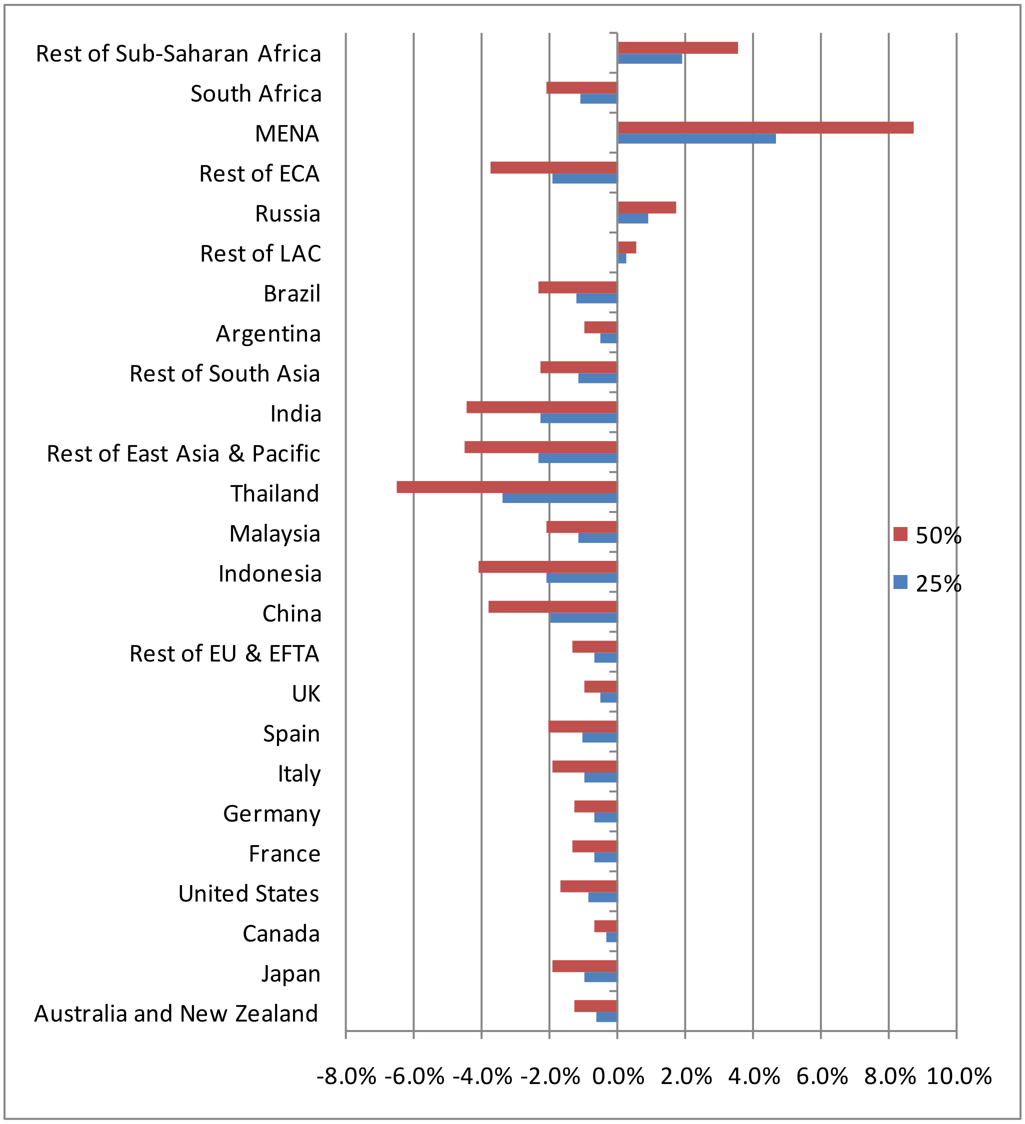
An increase in oil price would impact food supply in several ways. First, it diverts food commodities that are suitable as biofuel feedstock (e.g., corn, sugar, wheat) towards biofuel production. Second, it reallocates lands used for the cultivation of food commodities that are not suitable as biofuel feedstocks (e.g., rice) and pasture needed for animal grazing towards biofuel feedstock commodities (e.g., corn, sugar cane). Third, higher oil price could reduce demand for food that is reflected in the supply as demand and supply are balanced in the market equilibrium. Figure 6 presents the impacts of oil price changes on food supply. The reductions in food supply are significant. For example, a 25% increase in oil price would reduce global food supply, including processed foods, by 0.7% in 2020. If the price of oil doubles from its baseline level, it would reduce global food supply by 2.8% in 2020.

Figure 6: Impacts of oil price increase on global food supply by 2020 (% change from the baseline)



Even small reductions in food supply could exacerbate hunger and food deficits. Figure 7 displays the change in food supply by country/region in 2020 if the price of oil is 25% and 50% higher than in the baseline. Some of the countries or regions that are currently major suppliers of food crops could face significant drops in food supply by 2020. If the price of oil is 50% higher in 2020, food supply could plummet by about 4% or more in China, India, Indonesia, Rest of East Asia and Pacific and Rest of Europe and Central Asia, and by over 6% in Thailand.

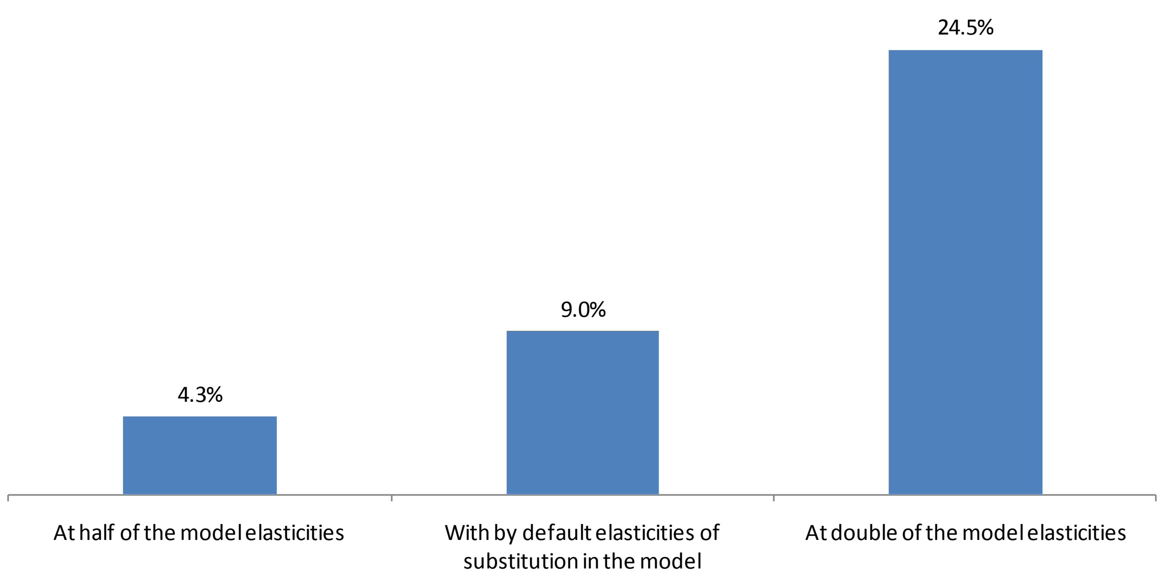
Figure 7: Food supply change by 2020 (% change from the baseline)



4. Sensitivity analysis on key model parameters

The level of biofuels penetration is highly sensitive to the degree of substitutability between biofuels and their fossil fuel counterparts (i.e., gasoline and diesel). We assumed the substitution elasticity between biofuels and their corresponding fossil fuel counterparts to be 2.4. In the sensitivity analysis, we double and also halve the elasticity of substitution between gasoline and ethanol (and between biodiesel and diesel) when we run the model. Figure 8 illustrates how the penetration of biofuels would change at the global level when the elasticity of substitution between biofuels and fossil fuels is changed. As can be seen from the figure, the penetration of biofuels increases by approximately two and a half times, from 9.0% to 24.5% in 2020, when the elasticity of substitution is doubled. The penetration of biofuels decreases by more than half, from 9.0% to 4.3% in 2020, if the elasticity of substitution is halved. This finding is very crucial from a policy perspective. If the substitution possibility between biofuels and fossil fuels increases in the future through the increased penetration of flex-fuel vehicles in the vehicle fleet, increases in price of oil would have even larger impacts on the expansion of biofuels. On the other hand, if the substitution possibility between biofuels and fossil fuels are limited, the impacts of oil price changes on the penetration of biofuels would be moderate.

Figure 8: Biofuel penetration under alternative values for elasticity of substitution when oil price is increased by 50% from the baseline



5. Conclusions and final remarks

One of the key concerns regarding biofuels is that a large increase in the price of oil would drive the rapid and large-scale expansion of biofuels, with devastating effects on land-use use as more and more land is allocated to the production of biofuels feedstocks. In order to investigate this question, this study uses a multi-country, multi-sector, recursive dynamic, global computable general equilibrium model to simulate various future oil price scenarios and assesses the corresponding impacts on biofuels production, agricultural outputs, land-use change and global food supply. The study shows that if the world oil price were to increase by about 65% from the

2009 level of US$56/bbl to US$93/bbl in 2020 in the business as usual or baseline case, the share of biofuels (i.e., ethanol and biodiesel) in total liquid fuel consumption in the transport sector (or biofuel penetration) would increase to approximately 5.4% in 2020 from the current level of around 2.4%. If the price of oil in 2020 is 25% higher than in the baseline, the penetration of biofuels would reach around 7.2%; if oil price is doubled from the baseline level, the penetration of biofuels would reach 12.6% in 2020. Countries that would experience high levels of penetration include Brazil, India, Malaysia, Russia and the United States.

Although the penetration levels might look high, it should be noted that the assumed changes in oil price relative to the baseline also would be considered by many to be high, e.g., a doubling of oil price from its baseline in 2020 is a 230% increase from the 2009 level. Moreover, the penetration of biofuels is highly sensitive to the substitution possibility between biofuels and fossil fuels. If the elasticity of substitution is halved, the penetration of biofuels in 2020 would decrease by more than half. On the other hand, if the elasticity is doubled, the penetration of biofuels would increase by two and a half fold.

Increases in oil price would lead to reductions in agricultural output. If the oil price rises by 50% above its baseline level in 2020 (or 148% from the 2009 level), global agricultural output would drop by 1.5% from its baseline level. Note, however, that the agricultural output loss from a higher oil price would be even higher in the absence of biofuels, production of which provides incentives to increase agricultural output, thereby partially offsetting losses caused by the oil price rise. In Sub-Saharan Africa (with the exception of South Africa) and Malaysia, there would be a net increase in agricultural output. The study finds significant reallocation of land supply from rice, pasture and forest towards production of biofuels feedstocks (e.g., corn, sugar cane, wheat, oil seeds), thereby explaining why an increase in oil price would have only slightly negative, or even positive, impacts on agricultural output in the major biofuel producing countries.

Finally, our study shows that a 25% increase in oil price from its baseline level would reduce global food supply, including processed foods, by 0.7% in 2020. If the price of oil doubles from its baseline level (i.e., 230% increase from the 2009 level), global food supply would be reduced by 2.8% in 2020. Some of the countries or regions that are currently major suppliers of food crops, such as China, India, Southeast Asia and Eastern Europe, could face food supply reductions of 3.5-6.1% from the baseline by 2020.

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